High-resolution Ground Target Infrared Signature Modeling For Combat Target Identification Training

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Abstract

Recent world events have accelerated the evolution of the US military from monolithic formations arrayed against a known enemy, to a force that must respond to rapidly changing world events. New technologies are part of the Army's evolution and thermal imaging sensors are becoming more and more prevalent on the modern battlefield. These sensors are integrated into advanced weapon systems or commonly used for battlefield surveillance. Thermal imaging systems give the soldier the ability to deliver deadly force onto an enemy at long ranges at any time of day or night. The ability to differentiate friendly and threat forces in this situation is critical for the avoidance of friendly fire incidents and for the proper use of battlefield resources. The ability to foresee the location of the Army's next battlefield is becoming more difficult, and we don't know where the next battlefield will be from year to year. Infrared target recognition training tools need to be flexible, adaptable, and be based on not only the latest intelligence data but have geographically specific training available to the soldier.

To address this training issue, personnel of the Measurement and Signatures Division at the National Ground Intelligence Center have created the Simulated Infrared Earth Environment Lab (SIREEL) web site. The SIREEL web site contains extensive infrared signature data on numerous threat and friendly vehicles and the site is designed to provide country-specific vehicle identification training in support of US military deployments. The bulk of the content currently on the site consists of infrared signature data collected over a decade of intelligence gathering. The site also employs state of the art infrared signature modeling capabilities to provide the soldier in training the most flexible training possible. If measured data on a vehicle is not available, the website developers have the capability to calculate the infrared signature of ground vehicles in any location, any type of terrain, any weather condition, any operational state, at any time of day on any day of the year. This allows the SIREEL website developers to completely populate target signature training databases when measured data is unavailable for required vehicles. This paper explores the methodologies and tools necessary to provide the predictive infrared ground vehicle signatures for this application.

Introduction

When developing a concept for training soldiers how to interpret the output of an infrared sensor there are multiple critical issues to consider:

1) The training system must be able to provide information on any possible target that the soldier will encounter during a given deployment.
2) The training system should be able to be tailored to a particular deployment so that the soldier in training is not overwhelmed with learning requirements.
3) The signature data used to train the soldier must be of high quality and contain all meaningful feature information required to recognize a particular vehicle.
4) The vehicle signature data must be able to be presented as a part of a realistic infrared scene that is representative of the region of an impending deployment.

The four issues mentioned above define some of the basic requirements for an infrared signature combat identification training system. The first issue requires that the training system have a complete inventory of vehicles that a soldier can be expected to encounter on a given deployment. Gaps in the training system could lead to situations on the battlefield where a soldier encounters a target that is unknown to him and this could lead to delayed reaction times and increased risk to personnel.

The second major issue above, which relates to deployment-specific training, is important because the soldier should not have to attempt to retain information that is not relevant to his current mission. If he spends valuable training time memorizing signatures of vehicles that will not be encountered, his effectiveness is reduced and he is unnecessarily burdened with useless information. The signature of a vehicle in its original country of manufacture can be changed drastically due to the complex proliferation of military vehicles throughout the third world due to country-specific modifications. The soldier should have available the signatures of the vehicles as they appear in a particular country or region. For example, the Iraqi Type 69-II main battle tank (MBT) is a heavily modified Iraqi variant of a Chinese copy of a Russian T-55. While in many respects it is a T-55, its outward appearance is drastically different from the standard Russian MBT. To be effective, the training system should contain signature data on all the relevant variants and configurations of a given base vehicle.

The third training requirement issue is a basic quality requirement in that the signature data being used to present training information should be high quality signature data and be able to provide all pertinent IR feature information to the soldier in training. The data should represent as many operational states and environmental conditions as necessary. When a soldier views a target through an infrared sensor there are an infinite number of possible ways that a given target can appear. The target can have country-specific modifications and could possibly have some type of passive countermeasure such as camouflage employed. How the vehicle appears is also a strong function of the natural environment it is in, its operational state, the time of day, and the time of year. An infrared combat identification training system should be able to provide all of these signature states as needed for training.

The final general requirement for an infrared combat identification training system is the ability to present vehicle signatures imbedded in realistic infrared scenes representative of a specific region of interest. The vehicle detection and identification process is strongly dependent upon not only the signature of the vehicle itself but the scene clutter in which the vehicle resides. In addition, in many combat situations a target vehicle could be in defilade or partially occluded by objects in the scene. The ability to present partial signatures of vehicles is an important capability for realistic training.

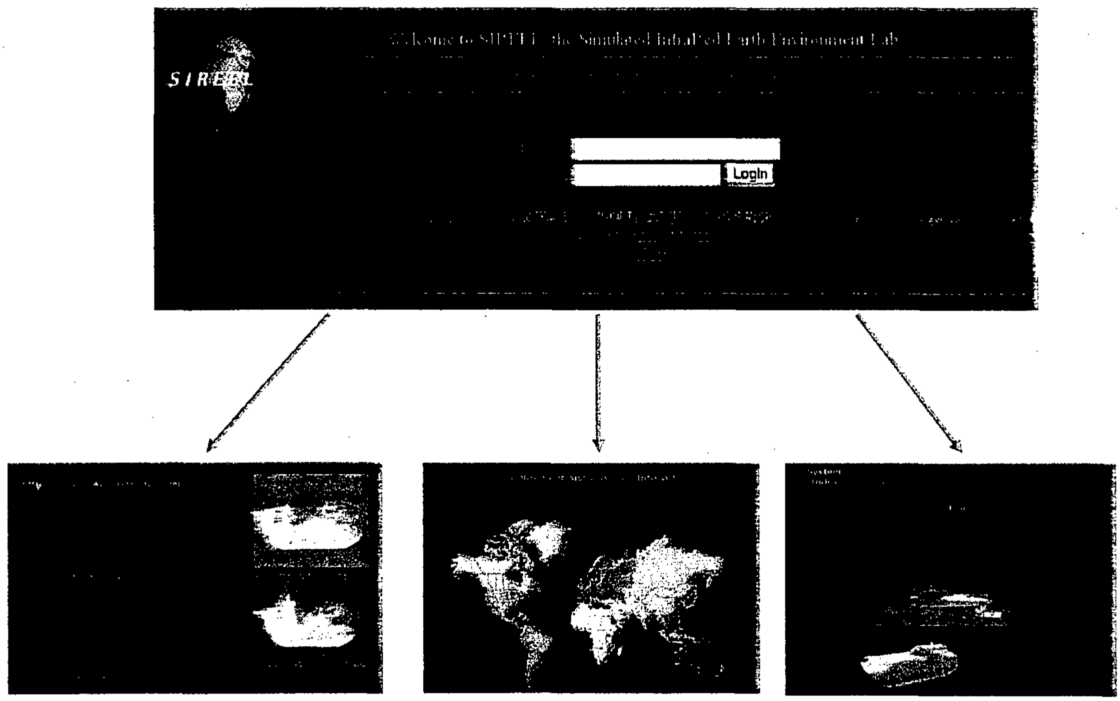
The infrared combat identification training requirements mentioned so far carry with them the implication that any training system must have an incredibly large number of signatures available for adequate training. This is driven by the large number of military vehicles presently in existence that could be encountered on a battlefield, the different signature states of each vehicle, the variants of each vehicle, and a given vehicle's configuration. While using measured signatures is the obvious place to start with a training system, it is simply not possible to collect signature data for every desired training scenario. Fortunately, there have been recent technological advances in the field of ground vehicle infrared signature prediction and computer processing power so that it is now feasible to address these signature requirements with predictive infrared signature models.

First principles of physics predictive infrared signature modeling provides the capability to calculate the infrared signature of a vehicle in any operational state, at any time of day or year, at any location in the world, and under the influence of any type of weather. Once a high-resolution predictive signature model has been built it can be used to generate as many signatures as required for training. These predicted signatures can be validated against measured signatures and there are numerous examples over the history of this field where it has been shown that it is possible to create a model that matches measured signatures very closely. Validated, computer-generated signatures offer a huge long-term cost savings over measured signatures. Currently on the SIREEL program it is possible to generate ground vehicle infrared signatures in volume at a cost in the tens of dollars per signature with a generation time measured in days. On the other hand, measured signatures could easily cost thousands of dollars per signature when the costs of vehicle operation, range time, and sensor costs are added up. A limited number of these relatively expensive measured signatures will be required for validation of the predictive models but once they have been validated to the required level of confidence, predictive models offer substantial cost savings.

SIREEL Website Overview

The SIREEL website consists of two major components, a general IR signature training section and a deployment section that provides country-specific information. The site is intended to provide simple, basic instruction on IR signatures while having an extensive and comprehensive database of vehicle signatures for the user to learn from as needed. A unique feature of SIREEL is the country-specific information that allows a user to learn about vehicles that will be encountered on any given military deployment. Figure 1 shows a conceptual layout of the SIREEL website.

SIREEL Secure Server Login Page



Infrared Signature Basic Education | **Country-specific Deployment Data** | **Extensive Vehicle Index**

Figure 1. SIREEL website contents and layout

The SIREEL site is currently accessible over the Internet and requires that a potential user acquire a login and password from the website administrator. The site is a secure site requiring 128-bit encryption but is unclassified and can be accessed from any military or government Internet domain. The SIREEL site is constantly being improved and populated with additional infrared signature data of ground vehicles, helicopters, and aircraft. Hundreds of vehicles must be represented to provide a comprehensive training set for target identification training with the primary focus being on ground vehicles such as tanks, infantry fighting vehicles, rocket launchers, and other primary battlefield targets. As mentioned previously, this requirement for signatures of exotic targets in locations all over the world necessitates the use of predictive IR signature modeling techniques that are based on first principles of physics.

SIREEL Infrared Target Signature Modeling

The use of predictive infrared signature models on the SIREEL website allows for the presentation of representative vehicle signatures for a vehicle at any time of day, in any weather condition, anywhere in the world. This capability is required in order to create geographically specific IR scenes for training. While measured IR signature data is very useful for demonstrating fundamental signature features of a vehicle, it is impossible to collect enough data to represent a vehicle's IR signature at every point in the vehicle's multi-dimensional signature space. This necessitates the use of predictive IR signature models.

The desired result of the ground vehicle IR signature modeling process is to end up with a 3D model that can be manipulated over the web for training purposes. The model must be able to convey important information such as vehicle shape from different aspects and location of thermal features. The process for creating an IR web model of a vehicle consists of four major steps: creating a geometric representation of the vehicle, deriving a thermal mesh from the geometric reference, attributing the thermal mesh and creating a predictive signature model, and creating an optimized real-time model compatible with web browser visualization software. Figure 2 shows these steps and examples of models at each stage of the development process.

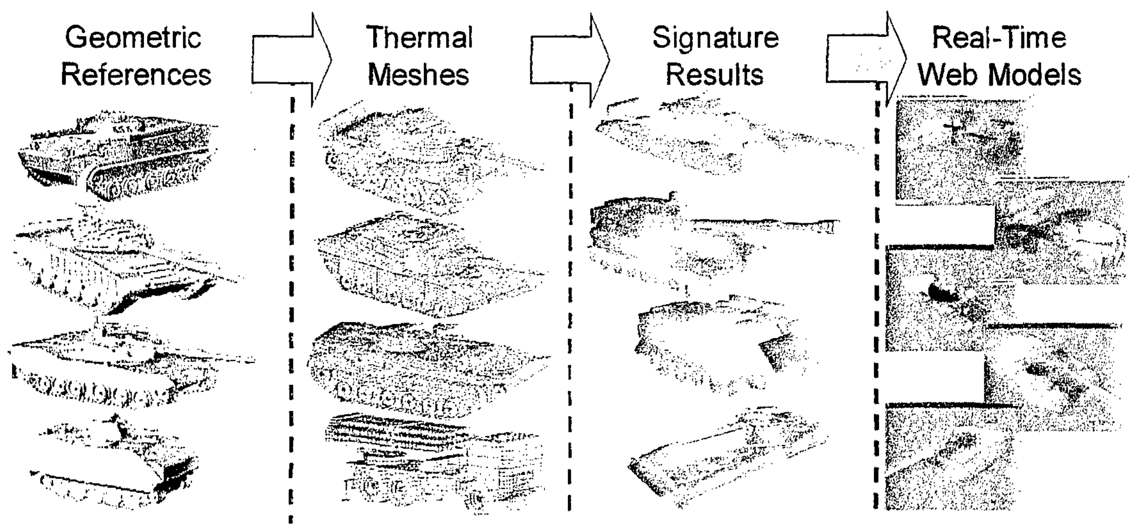


Figure 2. The Four Stages Required for IR Signature Web Models

The ground vehicle IR signature modeling process begins with the creation of a three dimensional geometric reference model of a vehicle. This has historically been a difficult task, but the speed and capabilities of personal computers, and the capabilities of modeling software have increased to the point where this stage of the development can be accomplished with commonly available tools. The most difficult challenge typically faced by a geometry modeler is building a model that is sufficiently accurate for a given application. Creating models for target training applications often involves vehicles about which very little is known. In some cases assumptions must be made concerning the shape and size of components of the vehicle because the best information available may be photographs. In other cases, accurate line drawings or examples of the actual vehicle may be available and the accuracy of the model can be very high. Fortunately, IR signature models have less stringent spatial detail requirements than other types of signature models and IR signature models can be created with sufficient detail from relatively limited information. The typical spatial resolution of the SIREEL predictive signature models ranges from three to five inches and non-critical features smaller than this are not modeled.

After the geometric reference has been created it is used as the primary inputs for the creation of a thermal mesh. The thermal mesh is simply another representation of the geometry of a vehicle but with very specific requirements. The thermal mesh must be created with low aspect ratio quadrilateral polygons in order to properly model the flow of heat across a vehicle component. In the final thermal solution, each polygon is assigned a calculated temperature over time based on a number of heat inputs over time, and each polygon is referred to as an isothermal node. The thermal signature codes have a finite limitation on the number of node temperatures that can be calculated at one time and this limitation drives the final resolution limits of the signature model. Figure 3 shows a typical thermal mesh created for the SIREEL website. The mesh shown in figure 3 is comprised of approximately 45,000 quadrilateral or triangular polygons.

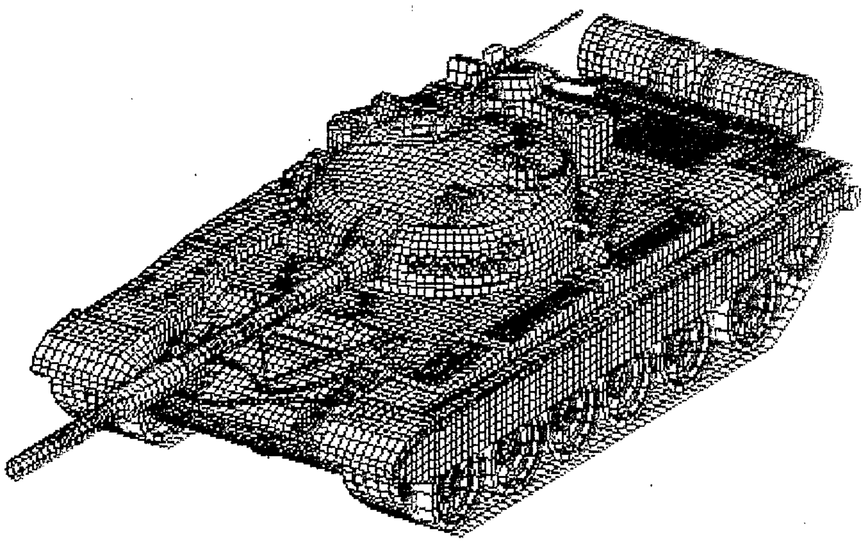


Figure 3. Typical Ground Vehicle Thermal Mesh

After the thermal mesh has been generated and segmented into appropriate groups, the mesh is used as the primary input to a signature prediction code. The currently available choices for ground vehicle signature prediction codes are the Physically Reasonable Infrared Signature Model (PRISM), and the Multi-Service Electro-optic Signature (MuSES) code. PRISM is a code that has been the historical standard for ground vehicle signature prediction and MuSES is the recent intended replacement for PRISM. MuSES is the more modern code with a more user friendly interface but it is a proprietary code and the user does not have access to the source code. This lack of access to source code makes it difficult for the user to model complex heat transfer processes such as the ones occurring in vehicle engines. PRISM source code is available and this allows the PRISM user to create whatever functions and subroutines necessary to model whatever is required. However, due to its more modern software architecture MuSES can accommodate models with higher numbers of thermal nodes and this allows for higher spatial resolution models. The approach used for the SIREEL infrared signature models is a hybrid process that takes advantage of the strengths of both codes. A custom version of PRISM was created that can accommodate more nodes than the standard release version of PRISM, and for relatively low node count models, PRISM was used to generate the IR signature. For models with higher node counts, PRISM was used to calculate the temperatures of engine components and temperature curve files were written out for importing into MuSES. MuSES calculates environmental interactions, node to node conduction and node to node radiation exchange. These fundamental heat transfer calculations combined with the engine component temperature curves from PRISM represents a highly flexible hybrid approach to ground target IR signature generation.

The engine, drive train, and running gear of a ground vehicle are the dominant contributors to a vehicle's IR signature in most tactical scenarios. The heat generated by the engine and drive train propagates from these active components to other parts of the vehicle by complex radiation, conduction, and convection paths. The temperatures of the components of the running gear (wheels and tracks) of a ground vehicle are driven by parameters such as the speed of the vehicle, mass of the vehicle, terrain type, and bearing friction. All of these complex heat transfer mechanisms must be addressed in order to accurately calculate the IR signature of an active ground vehicle. Figure 4 demonstrates the general process for the incorporation of detailed engine models into ground vehicle signature models.

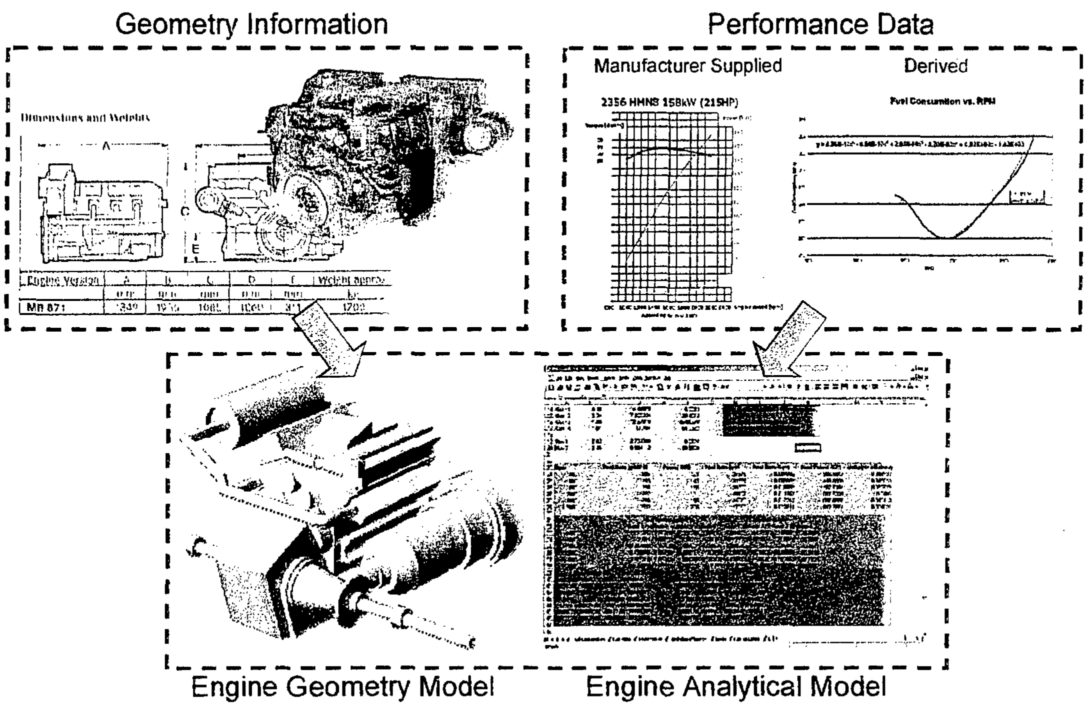


Figure 4. Engine Modeling for Ground Vehicle IR Signature Calculations

The engine modeling process begins with the collection of whatever data is available on the engine and drive train of the vehicle to be modeled. The first step is to create a three-dimensional model of the engine, generate a thermal mesh of the engine model, and incorporate the engine mesh into the vehicle thermal mesh. Analytical forms of the heat generation and heat transfer processes of the engine components must then be generated to create the software functions necessary to calculate the temperatures of the engine components. The code generation process begins with the collection of manufacturer-supplied automotive performance data or the derivation of these performance curves if they are not available. This data is then assembled and curve fitted in spreadsheets to create the equations necessary to generate code. These equations are used to modify the PRISM source code, which is then re-compiled and executed to generate either the vehicle IR signature, or the necessary heat curves to drive MuSES.

Once the relatively difficult task of engine modeling is complete, the mesh is attributed in either PRISM or MuSES, simulation scenario parameters are set, and a thermal signature calculation is performed. It is important to note that the IR signature of a vehicle is a strong function of its environmental and operational history, therefore the temperatures of vehicle components must typically be calculated over an entire day in order to obtain the signature of a vehicle at a single time during that day. Figure 5 shows six example IR signatures of a BM-21. The signatures down the left-hand side of the figure represent a solar loaded daytime (13:00) signature in the three operational states of cold, idling, and exercised. The three signatures down the right side of the figure represent the same operational states for a nighttime (02:00) signature. All six of these signatures were generated with three PRISM or MuSES runs with signature models being output for two discreet times during the simulation.

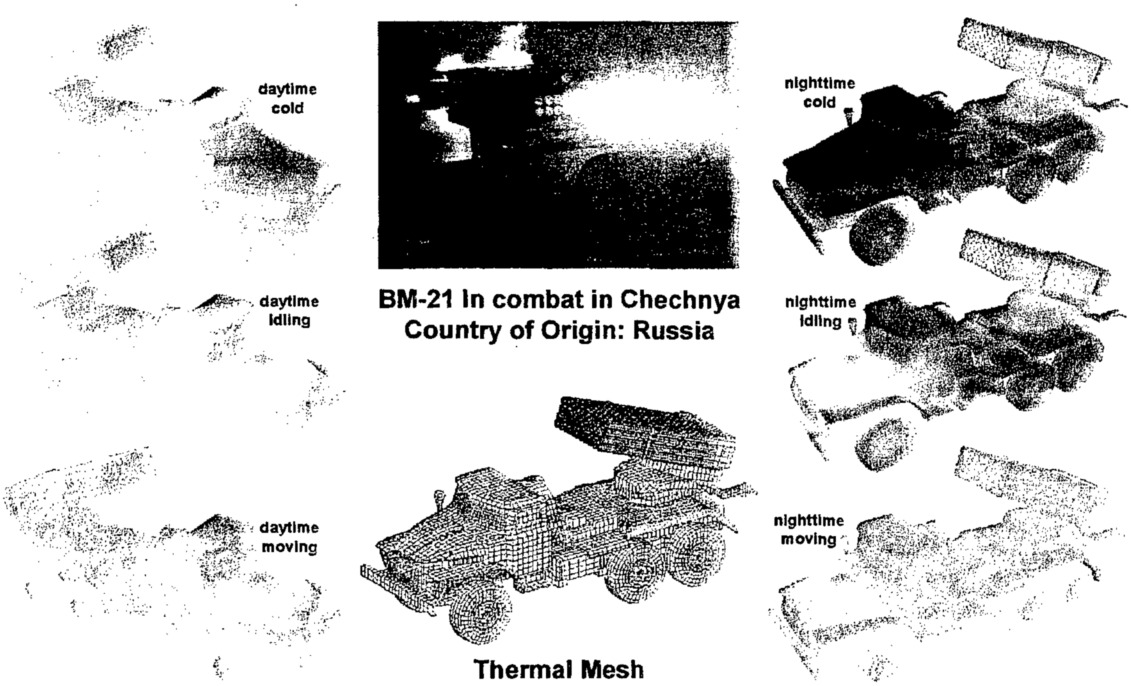


Figure 5. Example Ground Vehicle IR Signature Models

The different signatures shown in figure 5 demonstrate the power and flexibility of high-resolution predictive IR signature modeling. For example, the nighttime cold signature demonstrates passive radiative exchange between the vehicle model and the natural environment and between different sections of the vehicle itself. The flat surfaces that are exposed to the night sky appear colder and this is due to a net radiative heat loss to the sky from these components. Other sections of the vehicle that are shielded from the night sky, such as the area under the missile tubes, exchange thermal radiation with each other and stay relatively warm. The idling signature shows the effect of the engine heating on the hood and other front sections of the vehicle, and the moving signature model demonstrates wheel heating and the effects of forced convection on the vehicle. Forced, ambient air convection causes the hood of the vehicle to cool off and the relative thermal contrast between other parts of the vehicle is reduced as the forced convection heat rate becomes relatively dominant and attempts to force the temperatures of many components to the ambient air temperature. The solar-loaded signature on the left hand side of figure 5 demonstrates self-shadowing as the thermal shadow of the rocket tubes can be seen on the bed of the vehicle and the roof of the cab.

Summary

Figure 6 shows the current high-resolution infrared signature model inventory available for generating signatures for the SIREEL website. All of these models were generated over approximately an 18 month period and more models are being generated at a very rapid rate thanks to the development of long lead time software and personnel infrastructure. The multipliers in the figure, for example "x6", mean that models of six major variants of that base vehicle have been produced.

The SIREEL website is currently available for IR combat identification training and it employs constantly evolving, state of the art techniques for generating infrared signatures of vehicles. Traditionally, ground vehicle signature models require many months to create. Due to the huge number of vehicles models that will be required for SIREEL, a highly efficient signature model assembly line has been set up and signature models are currently being created at a rate of two to three per month. Custom software tools have been created that allow for the rapid generation of real-time models from signature code outputs. The entire process results in a 3-D IR signature model that can be manipulated by a user in a web-browser over the Internet, and this initial technology implementation will be one of the basic tools used by SIREEL to train soldiers in infrared target recognition.

MBT's	**IFV's**	**APC's**	**MRL's**	**SPH's**	**Recon/Light Tanks**
T-55 (x6)	BMP-1	BTR-60	M-1991	M109	BRDM-2 (x4)
T-62 (x2)	BMP-2	M113	BM-21	2S1	PT-76
T-72		KIFV		2S3	
T-80 (x2)		MT-LB			
M1		BTR-50	**Anti Tank**	**AAA**	**SAM's**
M60			AT-3	ZSU-23/4	SA-9
K1			AT-5	ZU-23	SA-13
Chieftain			M-901	MT-LB/ZU-23	
				Gaz-66/ZU-23	

Figure 6. Q4 FY02 SIREEL IR signature model inventory